Int. J. on Recent Trends in Engineering and Technology, Vol. 9, No. 1, July 2013

Frequency Dependent Characteristics of OGMOSFET

Gayatri M Phade[1], Dr B. K. Mishra[2].
[1] SNDT University, Mumbai, India
Email: gphade@gmail.com
[2] Thakur Engineering college, Mumbai, India
Email: drbk.mishra@thakureducation.org

***Abstract*— Miniaturization in length, lowering of power, increase in package density and sensitivity to light of MOSFET leads it as the potential candidate for RF application. As device is expected to operate at RF, it is essential to observe its frequency dependent characteristics at RF. In this paper frequency dependent electro optical characteristics of Optically Gated Metal Oxide Semiconductor Field Effect Transistor (OGMOSFET) are investigated numerically. Variation of drain current-voltage characteristics, gate capacitance and transconductance of OGMOSFET, with varying frequency, is reported. MOSFET having length of 0.35µm is selected for investigation, which is optically gated with incident radiations of optical power of 0.25mW and wavelength of 800nm. MATLAB is used as computational platform to test and tune the results. Results show that increase in modulating frequency of OGMOSFET decreases drain current, gate capacitance, transconductance and output conductance. This is due to decrease in life time of inversion charges at very high frequencies. Operating bandwidth of the device is up to 4GHz.**

***Index Terms*— Optically gated metal oxide semiconductor field effect transistor OGMOSFET, frequency dependent characteristics, electro-optical**

I. Introduction

CMOS devices are preferred for IC designing at RF range. It requires single polarity supply, having low cost and excellent RF integration capability. Many authors have investigated sensitivity of MOSFET to light, theoretically as well as practically [1, 2]. Initially optoelectronics implies involvement of III/V semiconductor materials. For the applications other than ultra high speed photodetectors or light emitters, III/V photodetectors and OEICs are found costly. Silicon photodetectors and receiver OEICs are the only choice when high volumes are needed. This is due to the advantages of monolithic optoelectronic integrated circuits like, good immunity against electromagnetic interference (EMI), reduced chip area, improved reliability, cheaper mass production, larger -3dB bandwidth [3,4].

In recent decades researchers are showing their keen interest in the development of an accurate and simple device model of the device at RF. Optical control to this device provides an additional port to control the device characteristics. George K[5] carried out theoretical investigation of light dependence of SOI MOSFET with non uniform doping. Increase in Photon flux density lower downs the surface potential barrier. There is reduction in threshold voltage with increase in intensity of illumination. Gate Metal of the FET is replaced by the absorption region. The drain to source current and the transconductance increases significantly with optical flux density. Abhinav Kranti [6], presented thin film fully depleted Surrounding/Cylindrical Gate (SGT) MOSFET model based on threshold voltage modeling. Increase in incident photon flux density, gives lowering of effective bulk charges and the channel barrier thereby decreasing the threshold voltage and increase in drain current. H C Kim [7], given experimental set up to study photonic characterization of capacitance voltage characteristics in MOS capacitors and Current – Voltage characteristics in MOSFETS. Photovoltaic effect changes threshold level and photoconductive effect increases channel conductivity. Modeling is based on interface states in MOS System and uniform distribution of trap levels is assumed, practically which may differ. Device used for simulation was long channel and operating range is in KHz only. S. J. Sang [8] presented the model based on interface states at Si/SiO2 hetrojunction for pMOS. He reported that MOS capacitance is less sensitive to light where as there is significant effect of illumination on drain current of MOSFET. M S Khim [9] presented experimental model, in which illumination of the device causes reduction in the potential barrier due to PIBL. Threshold voltage reduces logarithmically with increase in photon flux density and saturation of the drain current can be controlled optically. M Schlosser [10] reported impact ionization MOSFET as an optical detector; he used the concept of cascaded APD. Increase in drain current is due to the impact ionization and photon induced charge carrier generation. There is scope of improvement in current structure to reduce unintentional doping level of i-zone. This model provides simple and accurate expressions for characterization of the device which are helpful to understand physics of optical interaction in the device.

Extensive use of optical transreceiption demands more explanations about microwave interaction in the device. At microwave frequencies device may get oscillate resulting into inconsistent performance. B B Pal [11,12] has reported frequency dependant characteristics of GaAs OPFET. As per our knowledge frequency dependence of optically gated MOSFET is not reported yet. It is necessary to understand the behavior of the device at varying frequency. In present work electro-optical characteristics of OGMOSFET are investigated for variable frequencies. Photo voltages, drain current, transconductance of the device with constant optical power and modulating frequency have been investigated theoretically. Section II explores mathematical model for proposed device which will be frequency as well as bias

DOI: 01.IJRTET.9.1.503

Int. J. on Recent Trends in Engineering and Technology, Vol. 9, No. 1, July 2013

dependent. Section III discussed the reasoning of the device behavior at varying frequency. Conclusion if the discussion is given in section IV.

II. Modeling Technique

Optical radiations are made to incident on the gate of MOSFET along Y direction as shown in figure1.

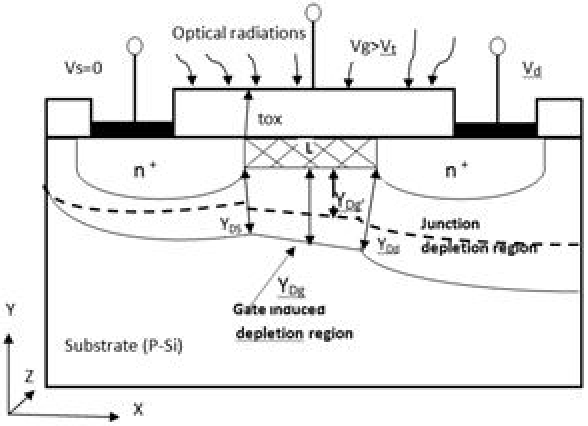

Figure1: Structure of MOSFET under illumination

Drain to source current flows in horizontal X direction. The e-h pairs are generated below the oxide layer due to photo absorption of incident optical radiations. Photo generation rate with space per unit volume is given by,

$$G = \alpha \emptyset e^{-\alpha y} \tag{1}$$

where, $\emptyset$: Photon flux density per unit area

α : Photon absorption coefficient per unit length

y : direction perpendicular to the surface

The optically generated carriers are given by the current continuity equation for electrons,

$$\frac{\partial n(y,t)}{\partial t} = \frac{1}{q}\frac{\partial Jn(y,t)}{\partial y} + G - \frac{n(y,t)}{\tau_n}$$

for holes,
$$\frac{\partial p(y,t)}{\partial t} = \frac{1}{q}\frac{\partial Jp(y,t)}{\partial y} + G - \frac{p(y,t)}{\tau_p} \tag{2}$$

where τ_n, τ_p Minority carrier life time which is same for electron and hole. The current equation consists of both drift & diffusion current and are given by-

$$Jn(y,t) = qV_y\, n(y,t) + q\, Dn\, \frac{\partial n(y,t)}{\partial t}$$
$$Jp(y,t) = qV_y\, P(y,t) + q\, Dp\, \frac{\partial p(y,t)}{\partial t} \tag{3}$$

Due to current densities, photo generated carrier moves along y-direction

V_y : drift velocity in y-direction is constant

$Dn,\ Dp$: diffusion coefficient of electrons and holes respectively.

Radiation flux density is modulated by the signal frequency 'ω' such that,

$$\varphi(\omega) = \varphi_0 + \varphi_1 e^{j\omega t} \tag{4}$$

Carrier generation due to absorption of light is,

$$G(\omega) = \alpha(\varphi_0 + \varphi_1 e^{j\omega t})\, e^{-\alpha y} \tag{5}$$

Equation 5 shows that carrier generation depends on flux density of incident radiation as well frequency of the signal. In depletion region, the carries flows due to the drift and recombination, in channel, the carries moves due to the diffusion and recombination.

Let $p(\omega, y)$ be the photo generated hole concentration which can be expressed as,

$$P(\omega,y) = \frac{\alpha\varphi_1\tau_{\omega p}}{(1-\alpha V_y \tau_{\omega p})} e^{-\alpha y} - \frac{N_t K_p \tau_p \tau_{\omega p} \varphi_1 \alpha}{S_p} + C\, exp\left(\frac{y}{v_y \tau_{\omega p}}\right) \tag{6}$$

where, S_p is the surface recombination velocity for holes and

$$\frac{1}{\tau_{\omega p}} = \frac{1}{\tau_p} + j\omega \tag{7}$$

Where ω is the frequency of incident radiations, $\tau_{\omega p}$ life time of minority carries under ac. Sidewalls of depletion region are assumed quarter arcs. Let $Y_{Ds},\ Y_{Ds}\ and\ Y_{Dd}$ be the depletion width at gate, source and drain side respectively, shown in figure 1. Modified gate depletion layer width under illumination can be calculated from equation [11],

$$Y_{Dg}'(\omega,y) = \sqrt{\frac{2\epsilon}{qN_a}\left(\emptyset_B - \delta + v(x) - v_{gs} - v_{op}(\omega,y)\right)} \tag{8}$$

In equation 8, $v(x)$ is the channel potential at that point, v_{gs} is gate to source voltage, v_{op} is photo voltage, $\emptyset_B$ is the bulk potential, and δ is the position of fermi level at the neutral region below the conduction band. The number of hole crossing the junction is given by [12-14],

$$P(\omega,y) = \frac{\pi}{4} Z\left(P_1 Y_{Ds}{}^2 + P_2 Y_{Dd}{}^2\right) \tag{9}$$

$$P_1(\omega,y) = \alpha\varphi_1 - \tau_{\omega p} e^{-\alpha Y_{Ds}};$$
$$P_2(\omega,y) = \alpha\varphi_1 - \tau_{\omega p} e^{-\alpha Y_{Dd}} \tag{10}$$

Generated optical voltage is given by,

$$V_{op}(\omega,y) = \frac{KT}{q}\, ln\left[\frac{qv_y P(\omega,y)}{J_{S1}}\right] \tag{11}$$

Pinch off voltage of OGMOSFET can be expressed as,

$$V_p(\omega,y)' = \left[V_{gs} + \left(\frac{KT}{q}\, ln\left[\frac{qv_y P((\omega,y))}{J_{S1}}\right]\right) - V_{TO} + V_{b2}{}^2\right]^{1/2} \tag{12}$$

where $V_{b2} = \left(\sqrt{\varphi_0} + \frac{\gamma}{2}\right)$ and γ is the body factor.

Equation 12 shows that pinch off voltage of Optically Gated MOSFET depends on channel width Z, optical flux density φ_1 and frequency ω. Drain-to-source current is expressed as,

$$I_D(\omega,y) = 2n(\omega,y)\mu c_{ox} V_T{}^2 \frac{W_{eff}}{L_{eff}} F\left(V_p(\omega,y), V_{D(S)}, V_T\right) \tag{13}$$

where L_{eff} and W_{eff} are effective length and width of device using channel length modulation (CLM), n is the function of pinch-off voltage and is length dependent due to reverse short-channel effect (RSCE), charge-sharing and drain in

DOI: 01.IJRTET.9.1.503

Int. J. on Recent Trends in Engineering and Technology, Vol. 9, No. 1, July 2013

duced barrier lowering (DIBL)[15,16]. Inversion charges are related to the small signal parameters like transconductance and gate capacitance. The transconductances and output conductance are given

$$\text{as,}\quad g_m(\omega,y) = \left[\frac{dI_{ds}}{dV_{gs}}\right] V_{Ds\ constsnt}$$
$$g_{ds}(\omega,y) = \left[\frac{dI_{ds}}{dV_{Ds}}\right] V_{Gs\ constant} \tag{14}$$

Gate capacitance of OGMOSFET is given by,

$$C_{gg}(\omega,y) = \frac{\partial Q_G(\omega,y)}{\partial V_G} \tag{15}$$

III. Results And Discussions

The results are simulated in MATLAB for MOSFET with L=0.35 µm and W=12 µm from 0.25µm CMOS process. Optical parameters are enlisted in table 1, as shown below.

Table I. Optical Parameters Of Ogmosfet

Symbol	Value	Unit	Description
α	10^6	/cm	Absorption coefficient
λ	800	nm	Wavelength of incident radiations
P	0.25	mW	Optical power
ø	10^{15}	Wb/m^2	Flux density
f	1-10	GHz	Operating frequency

Under dark condition drain current is analytically evaluated with model presented in [16] and results are same. Some variation is there due to change in parameter values. Under illumination drain current is computed with equation (13).

Figure 2 shows drain current increases with increase in optical power where as decrease with increasing modulating frequency. Figure 3 shows drain current increases with gate bias where as it decreases with frequency. Reduction in drain current leads to decrease in transconductance and output conductance of OGMOSFET. Results shown in figure 4 and 5 are the graphical interpretation of (14).

Increase in drain current with optical power is due to reduction in gate depletion width of the device with increasing optical power. Depletion width Y_{Dg} reduces to Y_{Dg}' as shown in figure 1 (dotted lines). With increasing frequency, depletion width goes on increasing as well as life time of charge carrier decreases. Increase in depletion width causes reduction in drain current and transconductance of OGMOSFET.

Figure 6 shows modulation of depletion width with frequency of 5 GHz, 6 GHz, and 7 GHz and incident power of 0.25 mW. Change in life time of hole with respect to frequency (1-10 GHz), is depicted in figure 7.

Frequency dependent behavior of capacitance reported by [1, 17] implies that capacitances of MOSFET decreases with increase in modulating frequency. Same is the performance of capacitance of OGMOSFET computed with (15) at frequency of 5, 6, 7 GHZ. It is well illustrated with Figure 7.

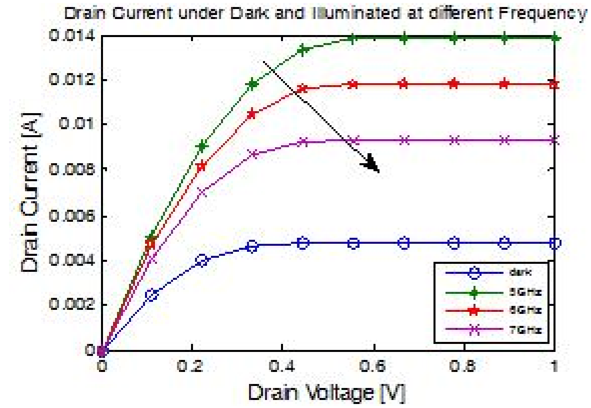

Figure 2 Drain Characteristics with Modulating Frequency

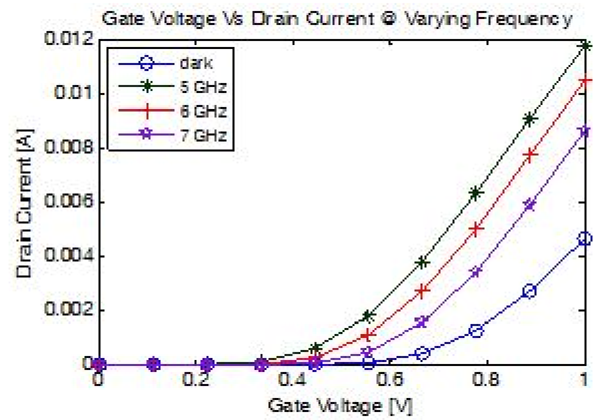

Figure 3 Gate Voltage versus Drain Current

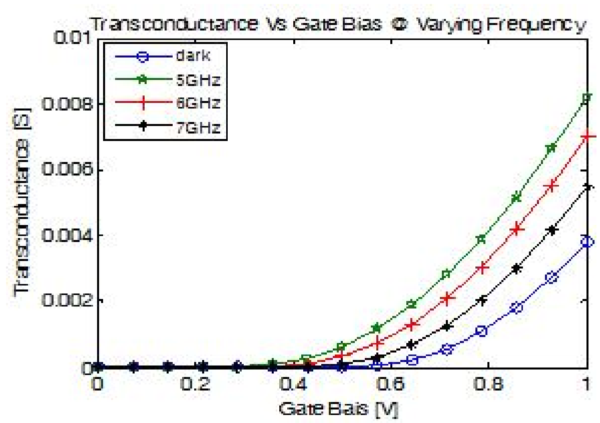

Figure 4 Transconductance Versus Gate Bias

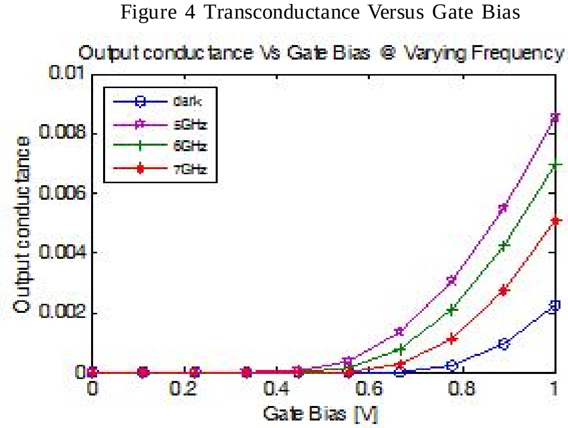

Figure 5 Output Conductance Versus Gate Bias

DOI: 01.IJRTET.9.1.503

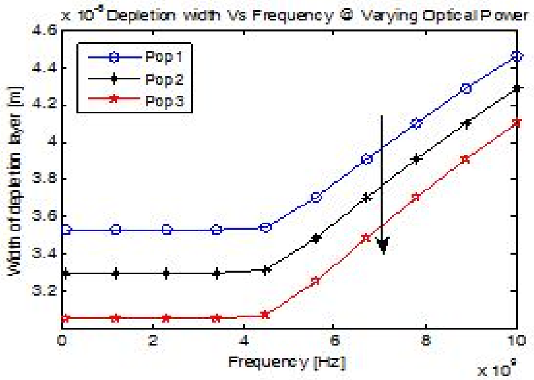

Figure 6 Depletion Width Modulation under Illumination Pop1=0.25mW, Pop2=2.5mW, Pop3=25mW

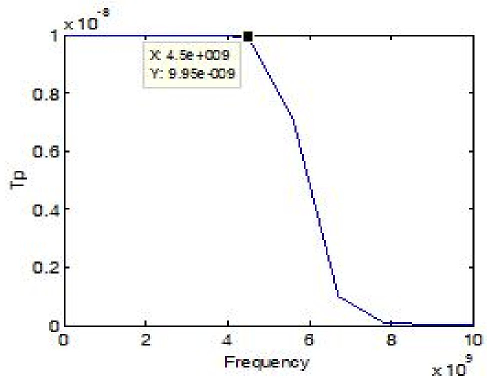

Figure 7 Life Time of Hole versus Frequency

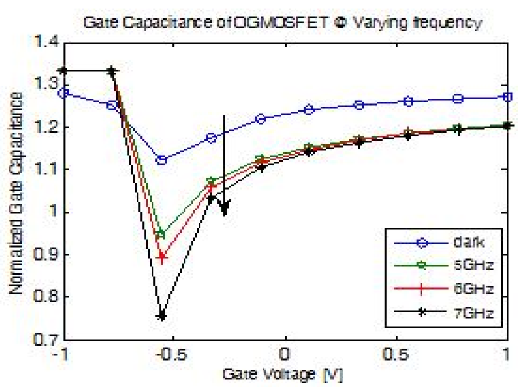

Figure 8: Gate capacitance of OGMOSFET with modulating Frequency

Conclusions

Frequency dependent characteristics of OGMOSFET is investigated at 5, 6, 7 GHz. At lower frequency i.e. up to 4 GHz, its characteristics are consistent. Above these frequency characteristics starts decaying. Higher is the frequency lower is parameter value of OGMOSFET. This is due to degradation of life time of minority carriers with increasing modulating frequency. Device is suitable to operate in 1 to 4 GHZ for optoelectronics applications.

References

[1] D. M. Kim, H. C. Kim, and H. T. Kim,' Photonic High-Frequency Capacitance–Voltage Characterization of Interface States in Metal Oxide Semiconductor Capacitors', IEEE Transactions On Electron Devices, Vol. 49, No. 3, March 2002,pp. 526-528

[2] Kazuhiko Shimomura, Tomonari Yamagata' Novel Integrated Photodetector on Si[S] Circuits optically controlled MOSFET', Vol.5, No.2, March/April 1999,pp 178-183

[3] Horst Zimmermann, 'Integrated Silicon Optoelectronics', second edition, Springer Series in Optical Sciences, London New York, 2009, ISBN 978-3-642-01520-5, pp 1-23

[4] S. M. Sze, 'Physics of semiconductor devices', Wiley INDIA, 2nd edition, New Delhi , 2007, ISBN 978-81-265-1104-4, pp 433-445.

[5] George K. Abraham, B.B.Pal, and R.U.Khan, 'Light Dependence of SOI MOSFET with Nonuniform Doping Profile', IEEE Transactions on Electron Devices, Vol. 47, No. 7, August 2000, pp. 1469-71

[6] Abhinav Kranti, S. Haldar, and R. S. Gupta, 'An Analytical Two-Dimensional Model for an Optically Controlled Thin-Film Fully Depleted Surrounding/Cylindrical-Gate (Sgt) Mosfet', Microwave and Optical Technology Letters / Vol. 28, No. 2, January 20, 2001, pp. 135-140

[7] H.C.Kim, H.T.Kim, S.D.CHO, 'Photonic Characterization of capacitance voltage characteristics in MOS capacitors and Current Voltage Characteristics in MOSFETS', Journal of the Korean Physical Society, Vol.40, No.1, January 2002,pp 64-67

[8] S. J. Sang, H. T. Kim, S. S. Chi, 'Characterization of interface states in MOS Systems by using Photonic high-Frequency Capacitance – Voltage Responses', Journal of the Korean Physical Society, Dec.2002, Vol.41, No.6, 892-895

[9] M.S.Khim, H.T.KIM, S.S.CHI, 'Distortion of Interface states in MOS System Extracted by the subthreshold current in MOSFET under Optical illumination', Journal of the Korean Physical Society, 2003, Vol.43, No.5

[10] M. Scholosser, P.Iskra , V.Abelein, 'The Impact Ionization MOSFET (IMOS) as low voltage optical detector', Nuclear Instruments and Method in Physics Research a 624,2010 pp.524-527

[11] B.B. Pal and S. N. Chattopadhyay, 'GaAs OPFET Characteristics Considering the Effect of Gate Depletion with Modulation Due to Incident Radiation', Journal on Electron Devices, Vol. 39, May 1992, pp. 1021-1027

[12] B. B. Pal, Shubha, R. U. Khan, 'Frequency Dependent Behaviour of an Ion Implaemented GaAs OPFET Considering the Photovoltaic Effect and the Gate Depletion Width Modulation', Solid state electronics Volume 38, No. 5 pp 1097-1102, 1995, pp.1097-1102

[13] Shubha, B. B. Pal, R. U. Khan, 'Optically controlled Ion-Implanted GaAs Mesfet Characteristic with Opaque Gate', Journal on Electron Devices, Vol. 45, January 1998, 78-84

[14] Dr. B.K.Mishra, 'Computer Aided modelling of solid state photodetectors, PhD thesis, Birla institute of technology', Mesra, Ranchi, 1995

[15] Alain-Serge Porret, Jean-Michel, 'A Compact Non-Quasi Static Extension of a Charge Based Model', IEEE Transactions on Electron Devices, Vol. 48, No. 8, August 2001, pp. 1647-1654

[16] Xiaojun Xu 1 , Lingling Sun, 'A Modified EKV Model for RF Application', IET International Conference on Wireless Mobile and Multimedia Networks Proceedings (ICWMMN 2006),ISBN: 0 86341 644 6, Nov 2006 page 71-74

DOI: 01.IJRTET.9.1.503